

Cloud Detection Exploiting Spectral Radiance Morphology in the Atmospheric Window 800-900 cm^{-1}

Rolando Rizzi* and Carmine Serio**

*University of Bologna

**University of Basilicata

Rationale behind the scheme

- Clear and cloudy sky spectra have a different shape because of the inhomogeneities introduced by clouds
- The different morphology is very pronounced in window regions because, e.g., of
 - a) - different background emissivity
 - b) - spectral structure

How to measure the degree of homogeneity between two spectra

- The task may be accomplished through the use of
 - Cross-correlation
 - Auto-correlation

What's the potential advantage to exploit morphological characteristics?

- Two clear sky spectra generated by different atmospheric profiles have the same shape. Independence of surface temperature, water vapour content.
- If a given spectrum has been diagnosed morphologically equivalent to a clear one, it means that the given spectrum may be considered for inversion on the basis of a forward model for clear sky

To begin with we start with a couple of radiance spectra,

$S_1(\sigma)$ *Observed Spectrum*

$S_2(\sigma)$ *Reference Spectrum*

First Step

Transform the two spectra in BT spectra

$$T_i(\sigma) = B^{-1}(S_i(\sigma)) \quad (1)$$

Remark:

this operation ensures that two spectra with different skin temperature may be made nearly coincident by a simple translation (invariance for translation) provided that the emitting background has the same spectral emissivity.

Second Step:

After BT conversion, $T_1(\sigma)$ and $T_2(\sigma)$ are standardized through the operation

$$H_i(\sigma) = \frac{T_i(\sigma) - \langle T_i \rangle}{S_i} \quad (2)$$

with $i=1,2$ and $\langle T_i \rangle$ and s_i the mean and standard deviation of $T_i(\sigma)$, respectively. The mean and standard deviation are considered with respect to the wave number σ .

Remark:

This operation makes the two spectra quite insensitive to variations because of different concentration, e.g., of water vapour.

Third Step

Compute correlation and cross-correlation

$$r_i(j) = \frac{c_i(j)}{c_i(0)} \quad (3)$$

$$r_{12}(j) = \frac{c_{12}(j)}{\sqrt{c_1(0)c_2(0)}} \quad (4)$$

$$c_i(j) = \frac{1}{N} \sum_{k=1}^{N-j} (H_i(k) - \langle H_i \rangle)(H_i(k+j) - \langle H_i \rangle) \quad (5)$$

$$c_{12}(j) = \frac{1}{N} \sum_{k=1}^{N-j} (H_1(k) - \langle H_1 \rangle)(H_2(k+j) - \langle H_2 \rangle) \quad (6)$$

with $i=1,2$; $\langle H_i \rangle$ is the average values of the standardized spectrum and, as usual, we have written $H(k\Delta\sigma) = H(k)$, with $\Delta\sigma$ being the sampling rate.

The *homomorphic index*, hs
which measure the homogeneity between the two spectra is

$$hs = \frac{\sum_{j=0}^{N_L} | (r_1(j) - r_2(j)) |}{\sum_{j=0}^{N_L} | r_{12}(j) |} \quad (8)$$

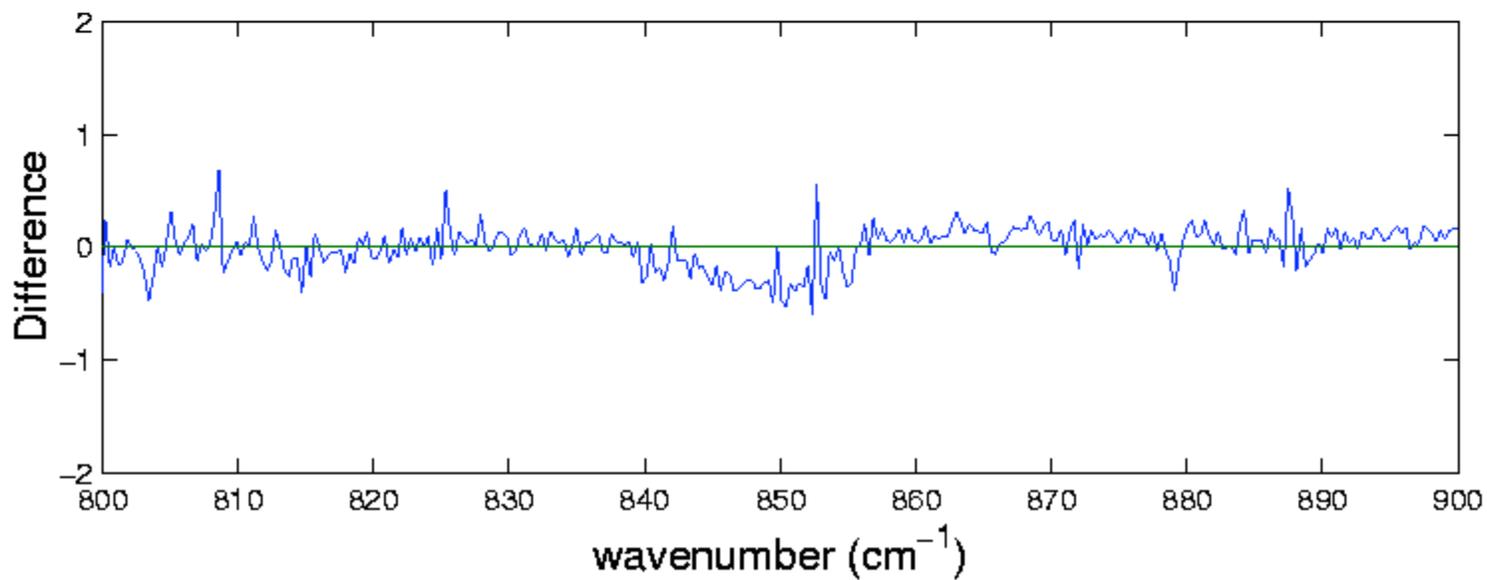
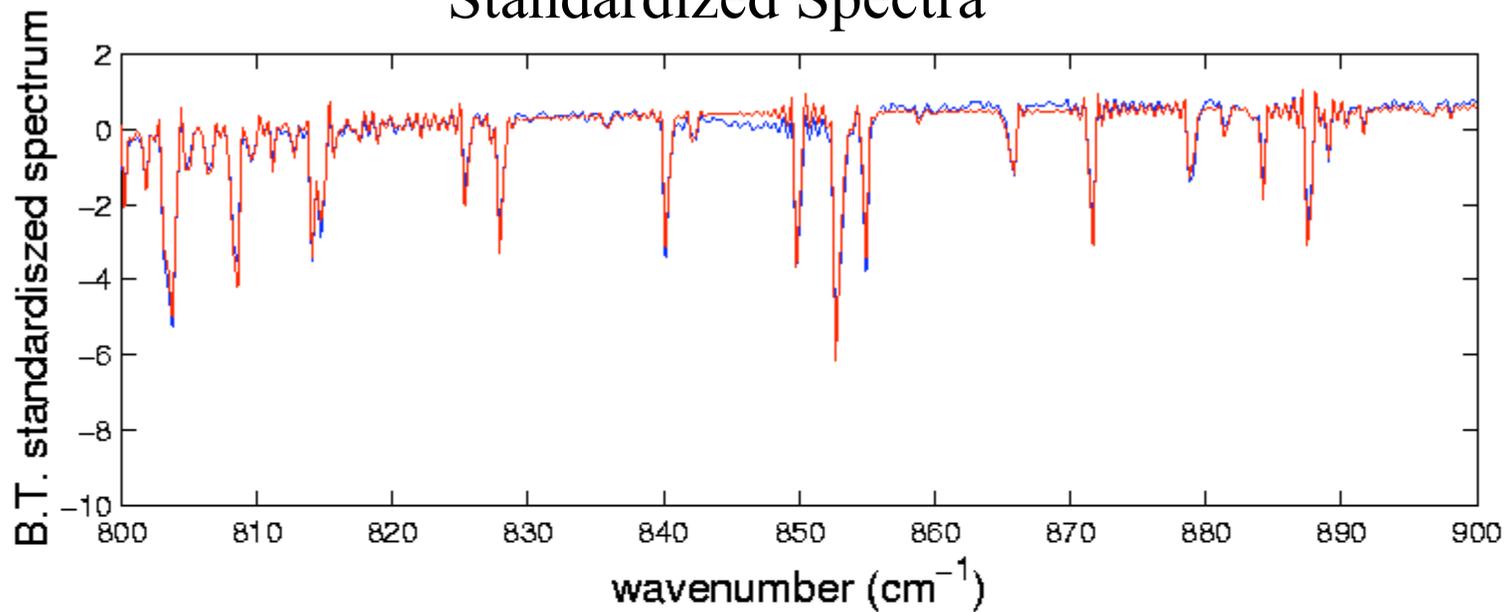
Application to IMG

- The above scheme has been successfully applied to IMG spectra
- A complete account is given in
- C. Serio, A.M. Lubrano, F. Romano, H. Shimoda, *Appl. Opt.*, Vol. 39, 3565-3572 (2000)

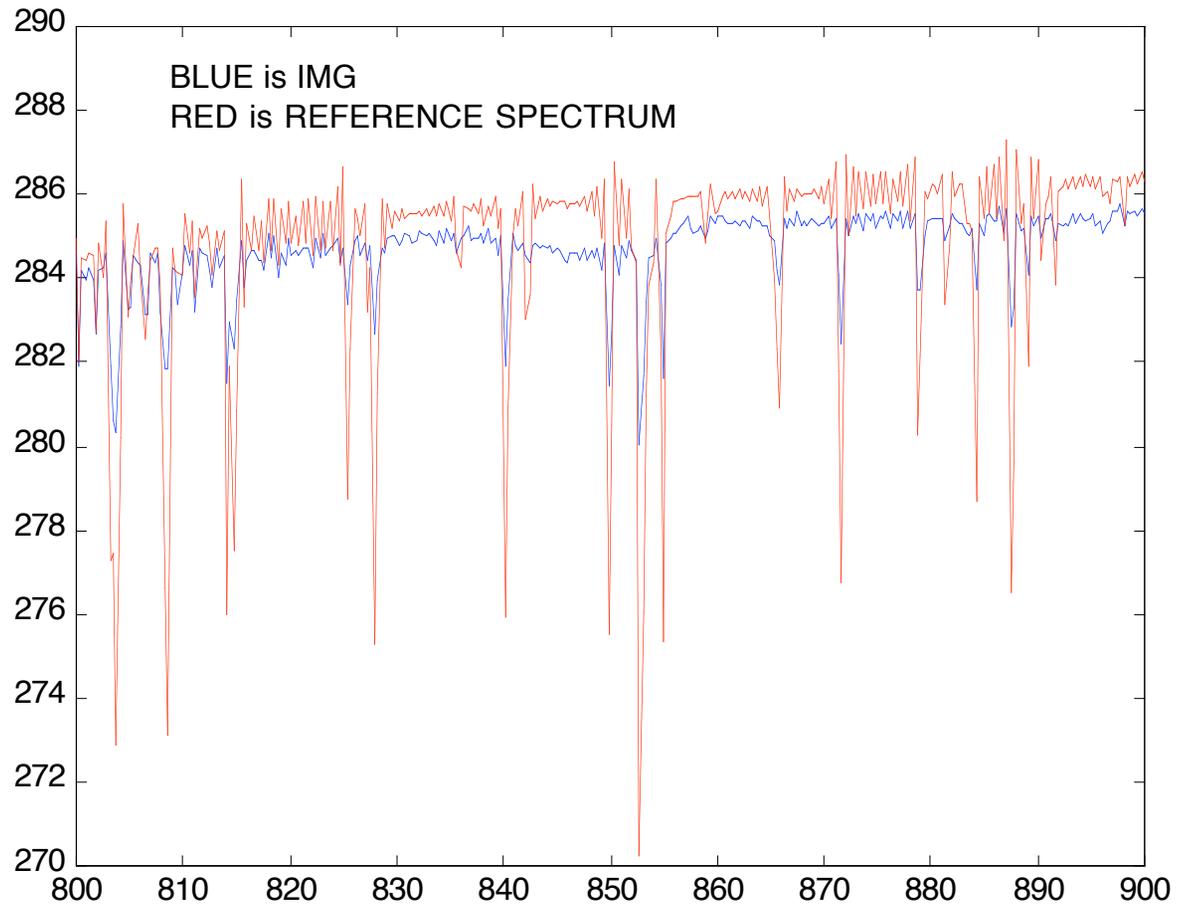
hs=0.12

IMG is blue

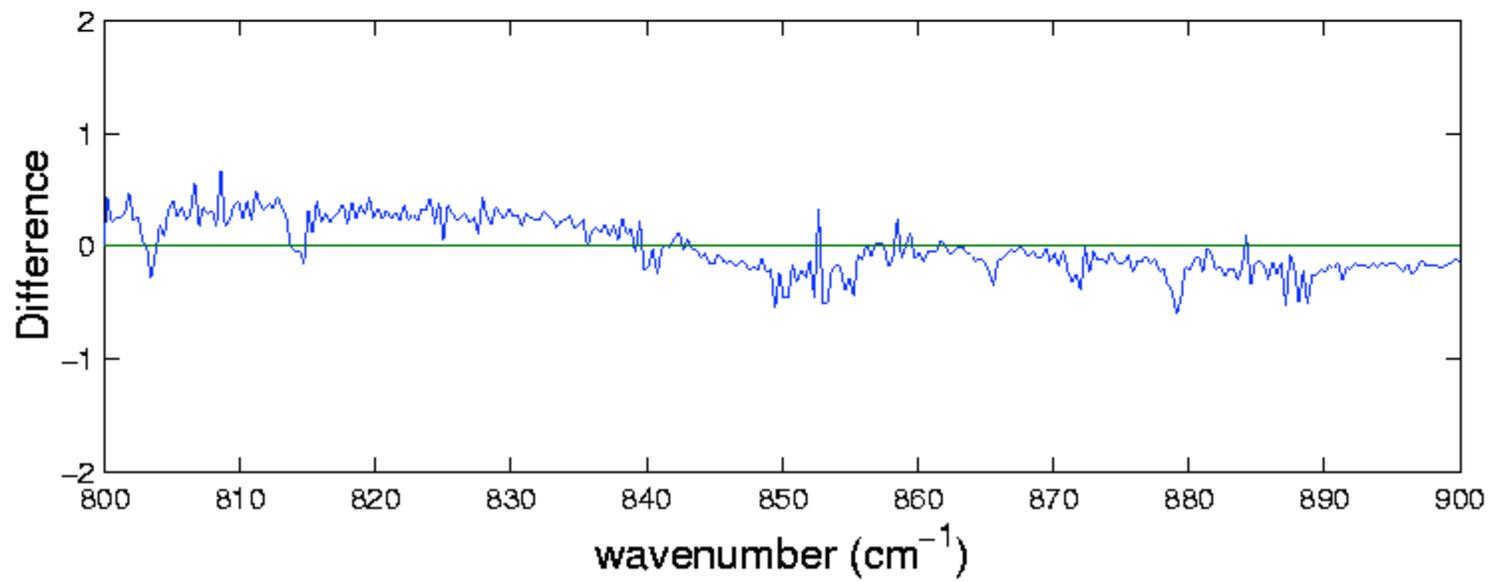
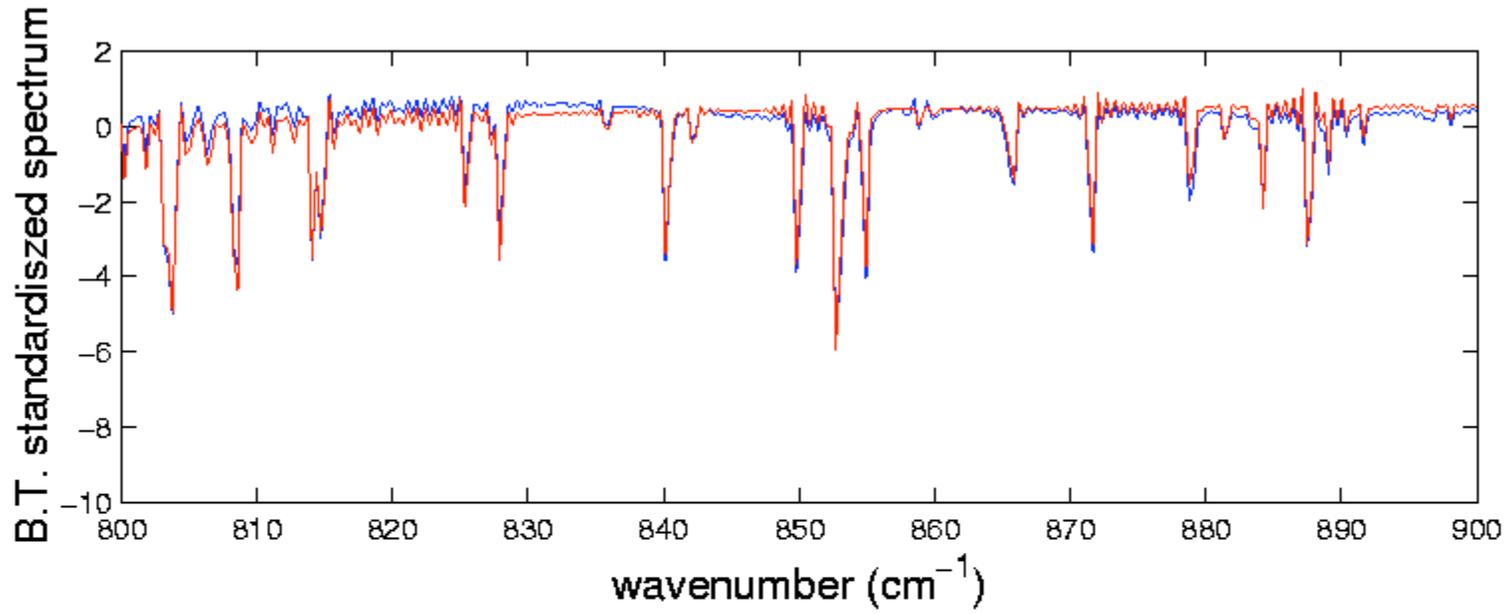
Standardized Spectra

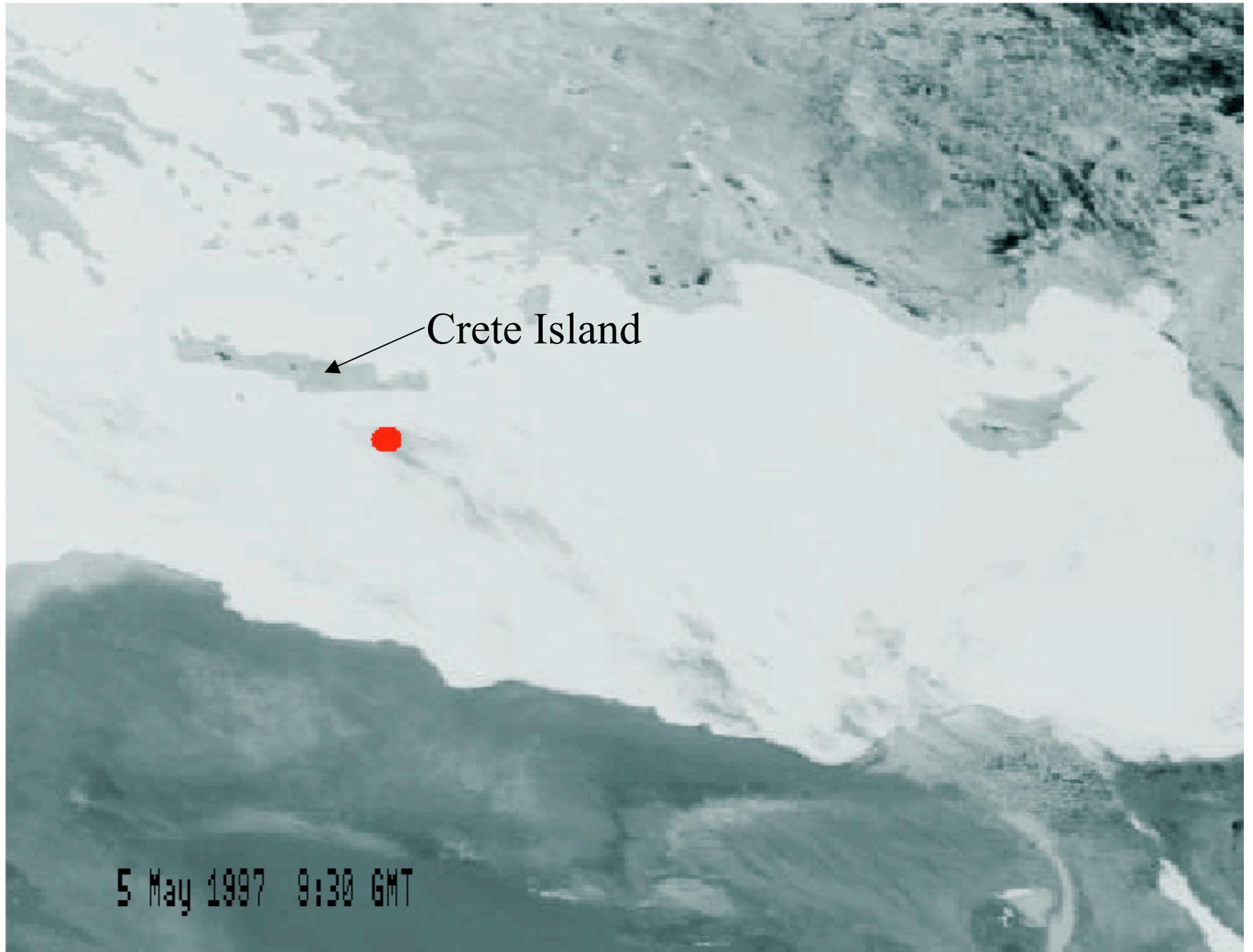


Spectrum recorded close to the Crete Island



hs=1.09





Crete Island

5 May 1997 9:30 GMT

Dependence of the homomorphic index hs on cloud amount

- The task has been addressed in simulation
- Using the line-by-line Hartcode* and RT3** forward model, spectral cloudy radiance has been computed for different cloud types

*F. Miskolczi, R. Rizzi, R. Guzzi, M. Bonzagni, in *IRS'88: Current Problems in Atmospheric Radiation*, A. Deepak Publishing, pp. 388_391 (1989)

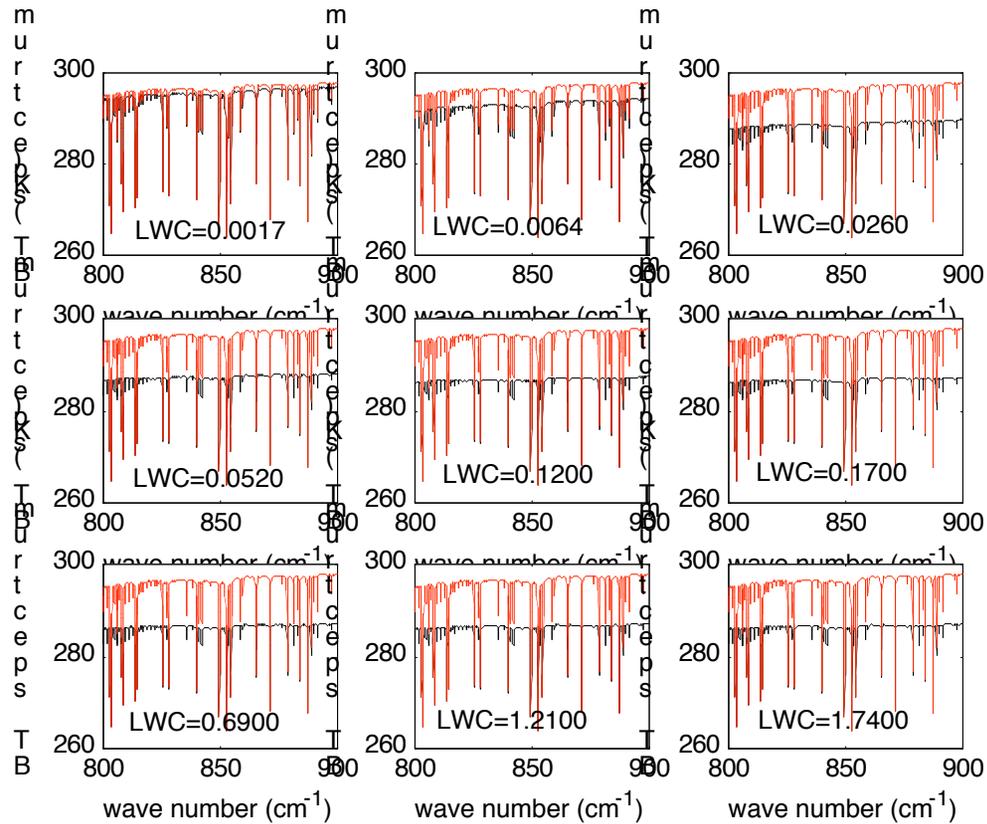
K. F. Evans and G. L. Stephens, *J. Quant. Spectros. Radiat. Transfer*, **46, 412-423 (1991).

- • **I1 cloud type**: an extra-high ice-cloud layer having properties denoted as I (next Table for details), located between 15.7 and 14.7 km;
- • **I2 cloud type**: an high ice-cloud layer having same I properties, located between 7.95 and 7.23 km;
- • **W1 cloud type**: a high water-cloud layer having WH properties between 5.9 and 5.3 km;
- • **W2 cloud type**: a medium water-cloud layer having WH properties between 4.1 and 3.5 km;
- • **W3 cloud type**: a low water-cloud layer having WL properties between 2.0 and 1.6 km.

Type	Effective radius R_{eff} (micrometers)	V_{eff}	Radius Range (micrometers)
I (ice)	30.	0.3	0.01-200
WH (water)	10.	0.125	0.01-200
WL (water, low stratus)	5.	0.2	0.01-200

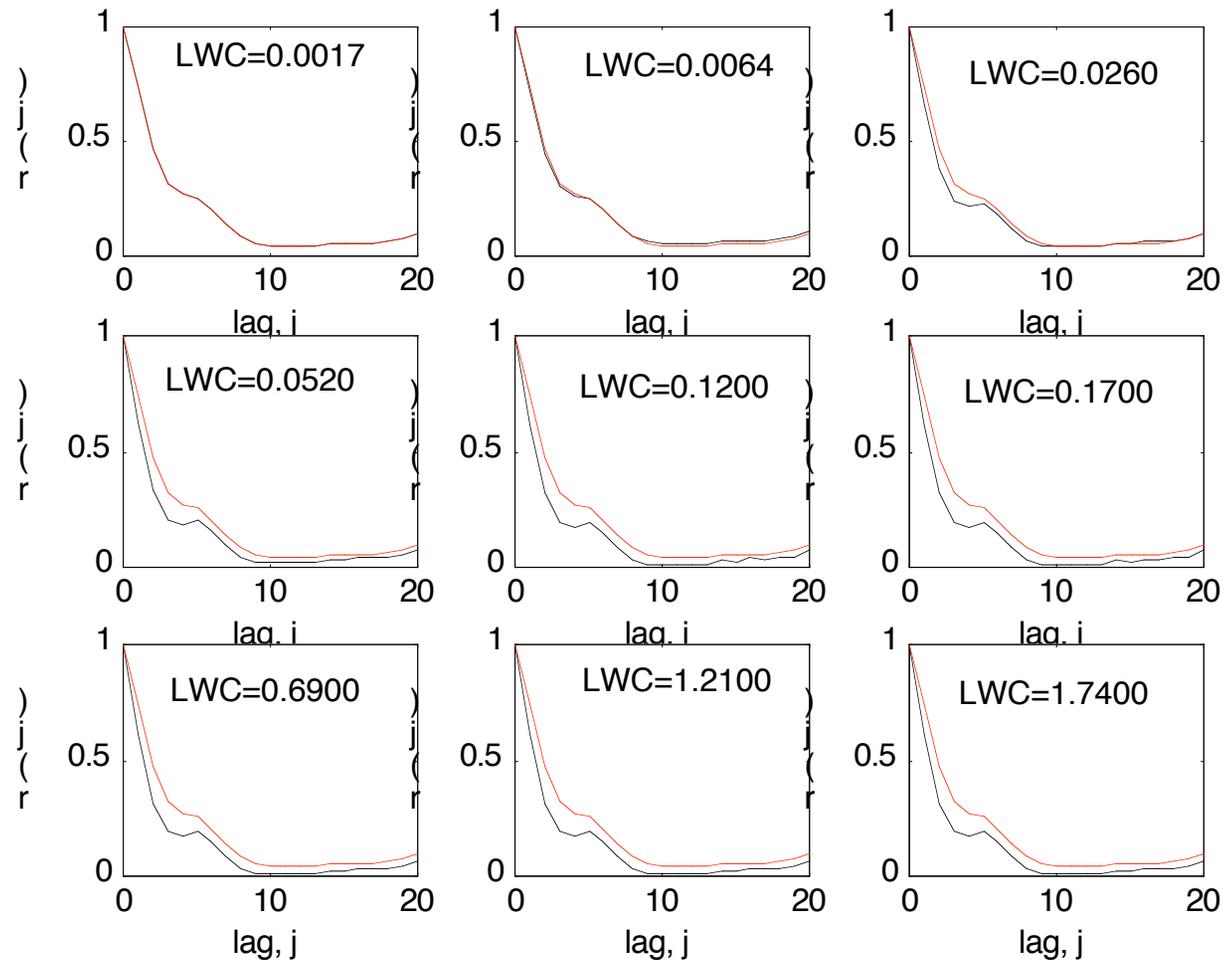
Water Low Clouds, Spectral Radiance as a function of LWC (g/m^3)

Reference in red, cloudy in black

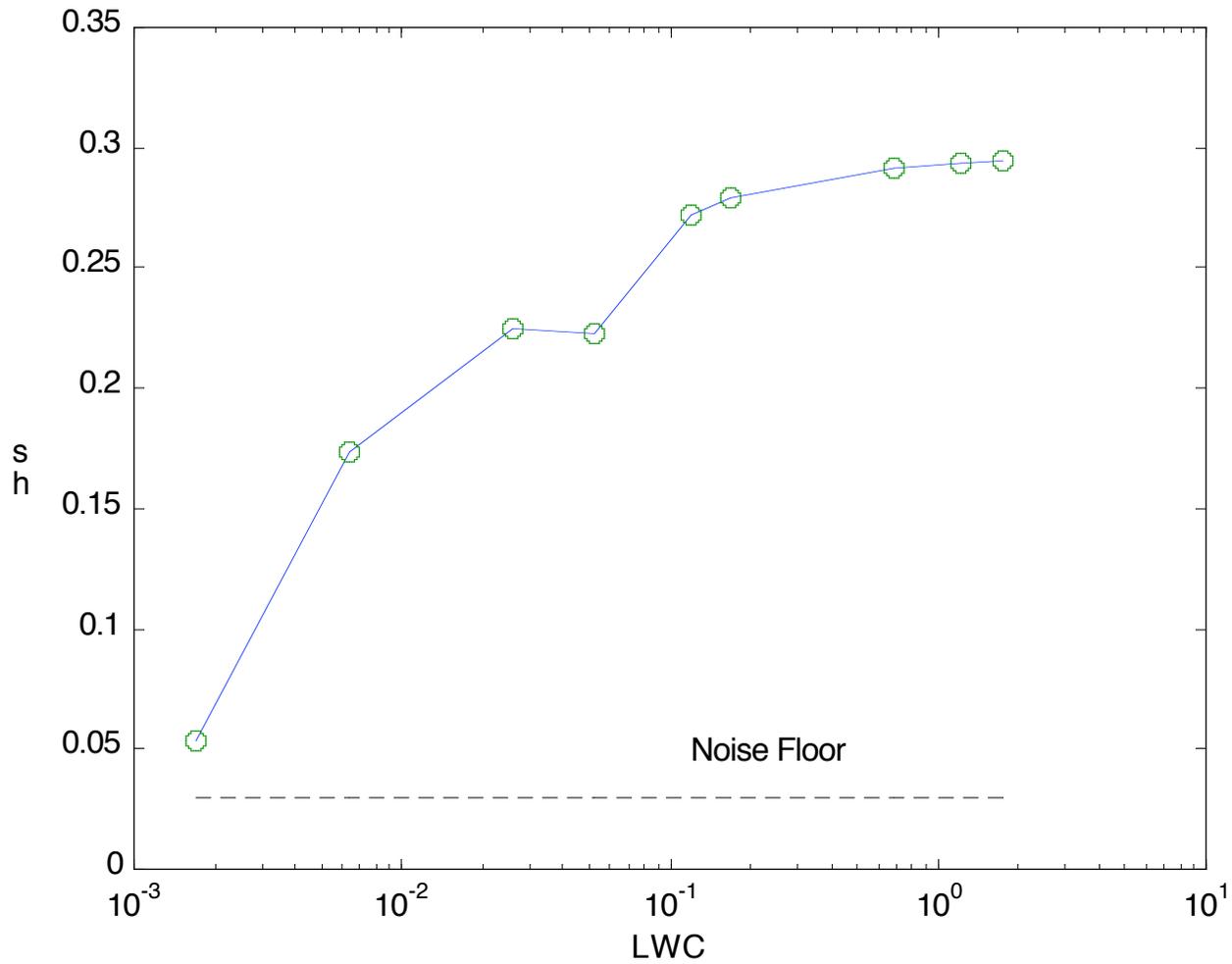


Water Low Clouds, auto-correlation as a function of LWC (g/m^3)

Reference in red, cloudy in black

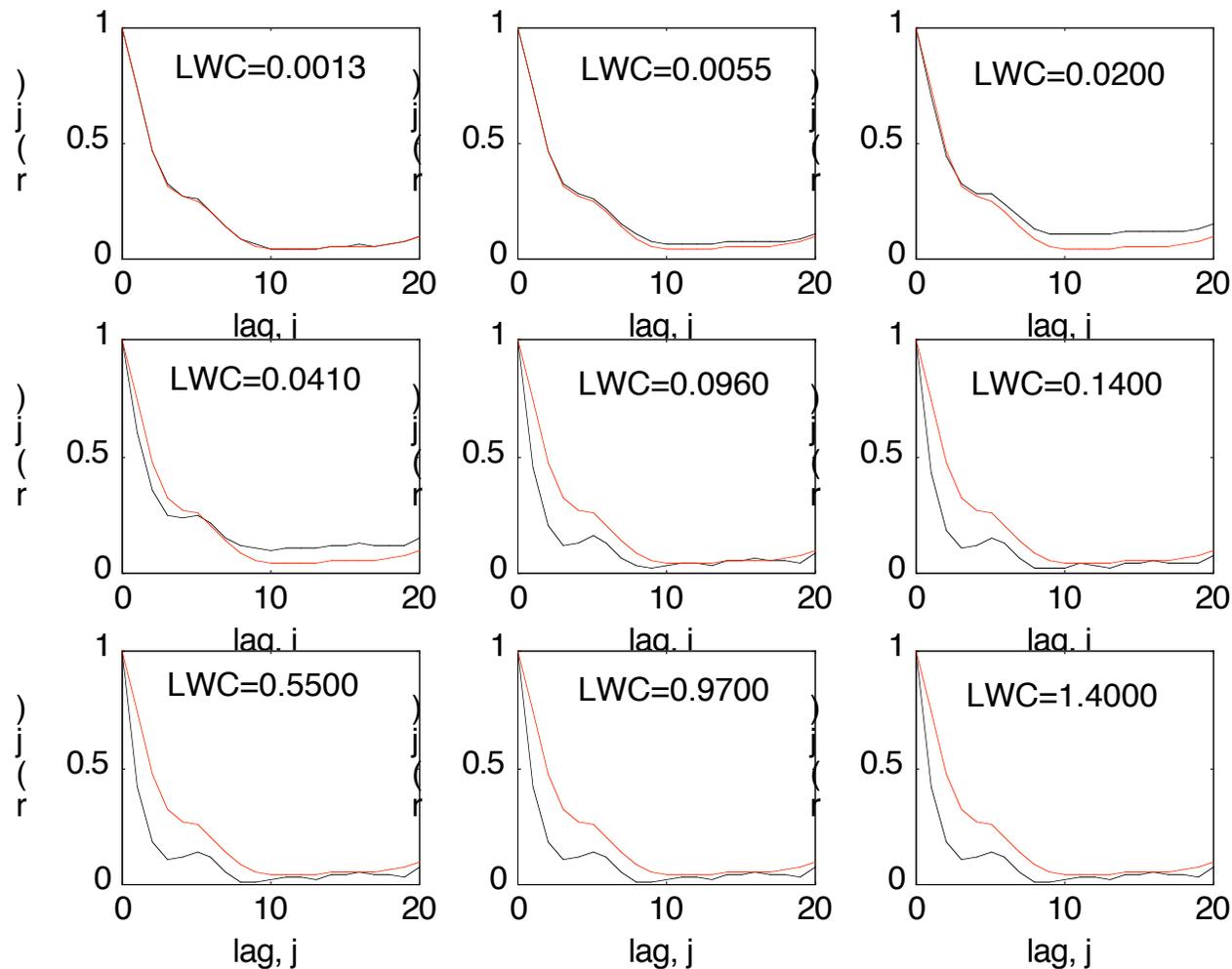


Water Low Clouds, *hs* vs. LWC (g/m³)

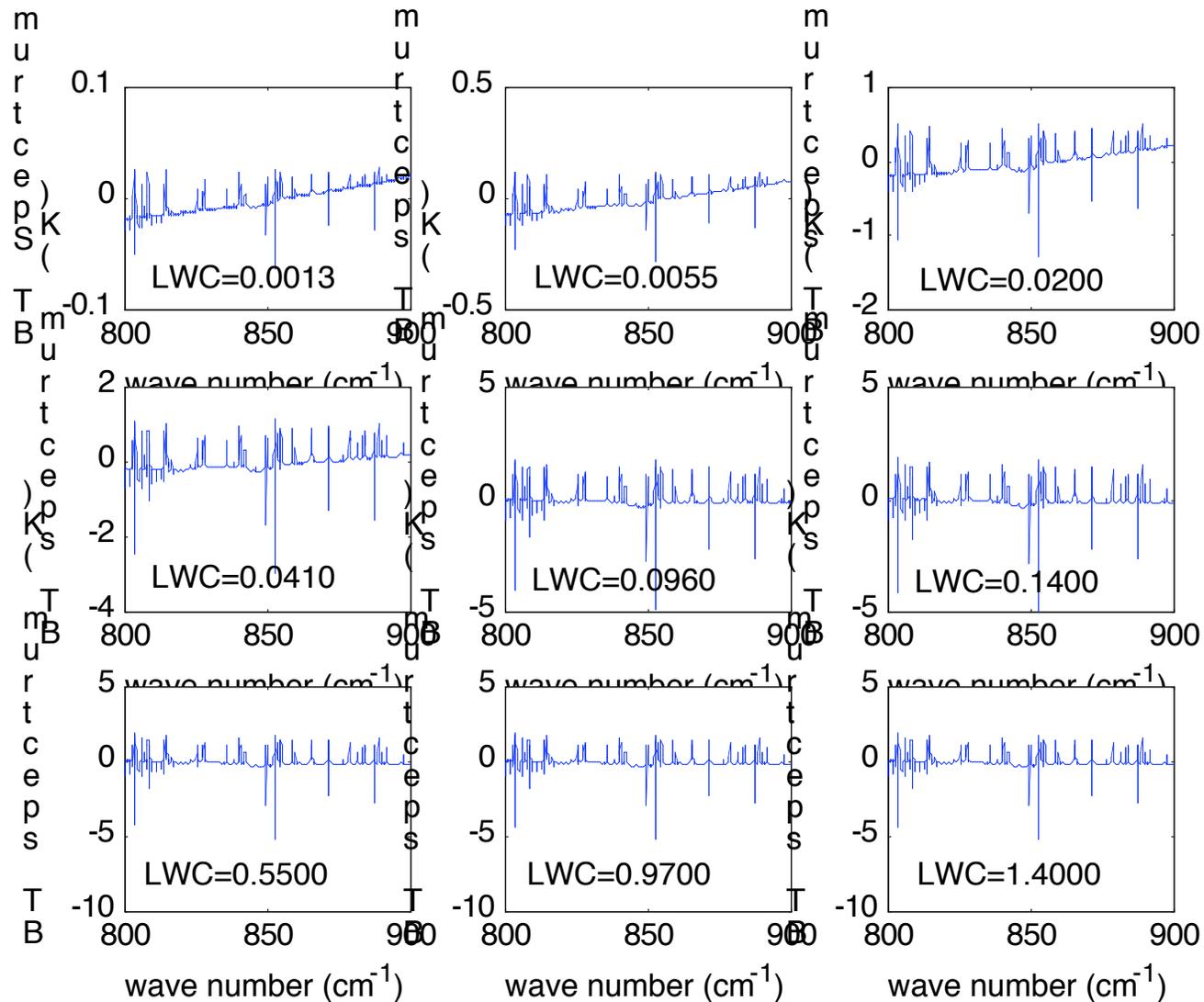


Water Medium Clouds, auto-correlation as a function of LWC (g/m^3)

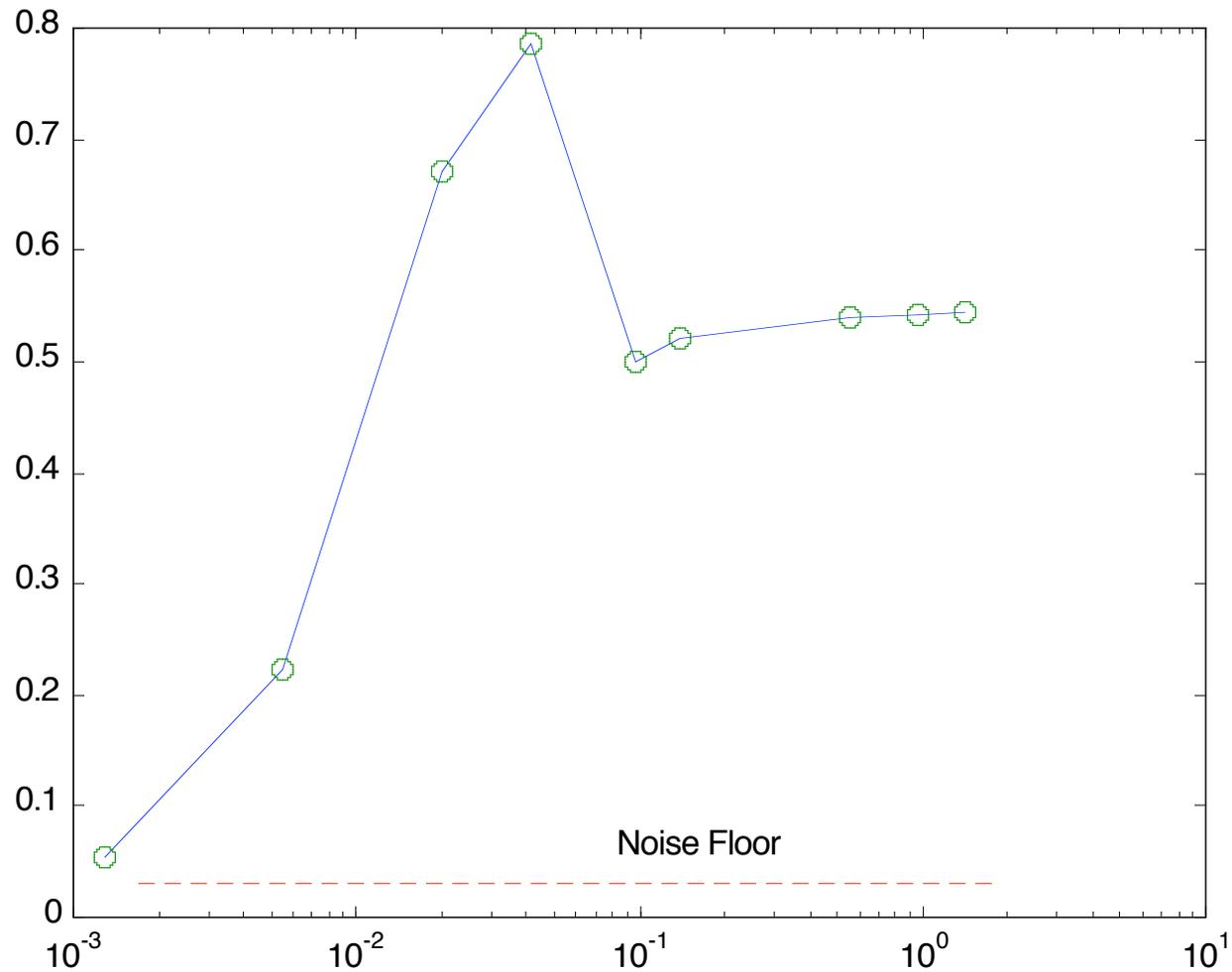
Reference in red, cloudy in black



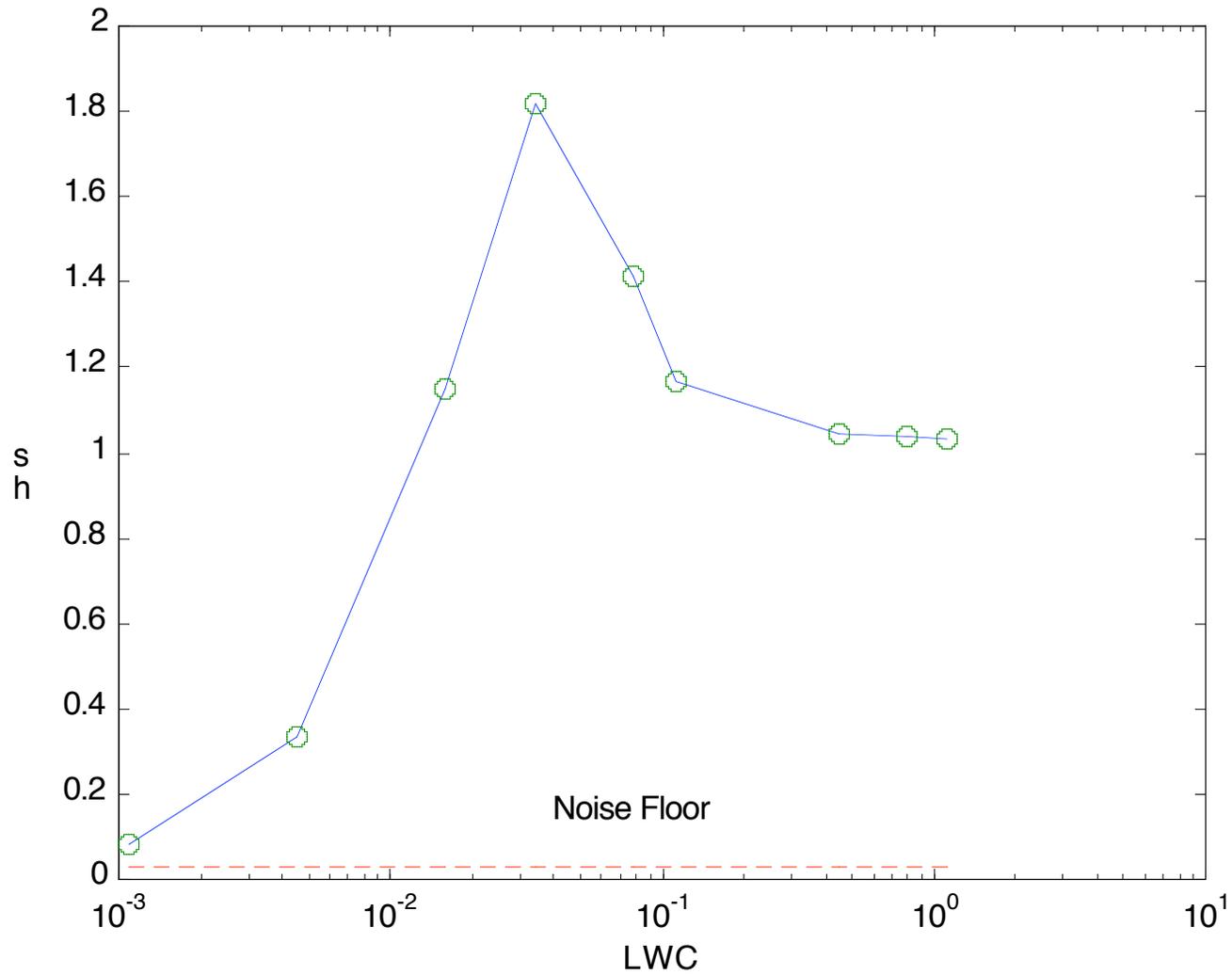
Water Medium Clouds, Difference of Standardized spectra as a function of LWC (g/m^3)



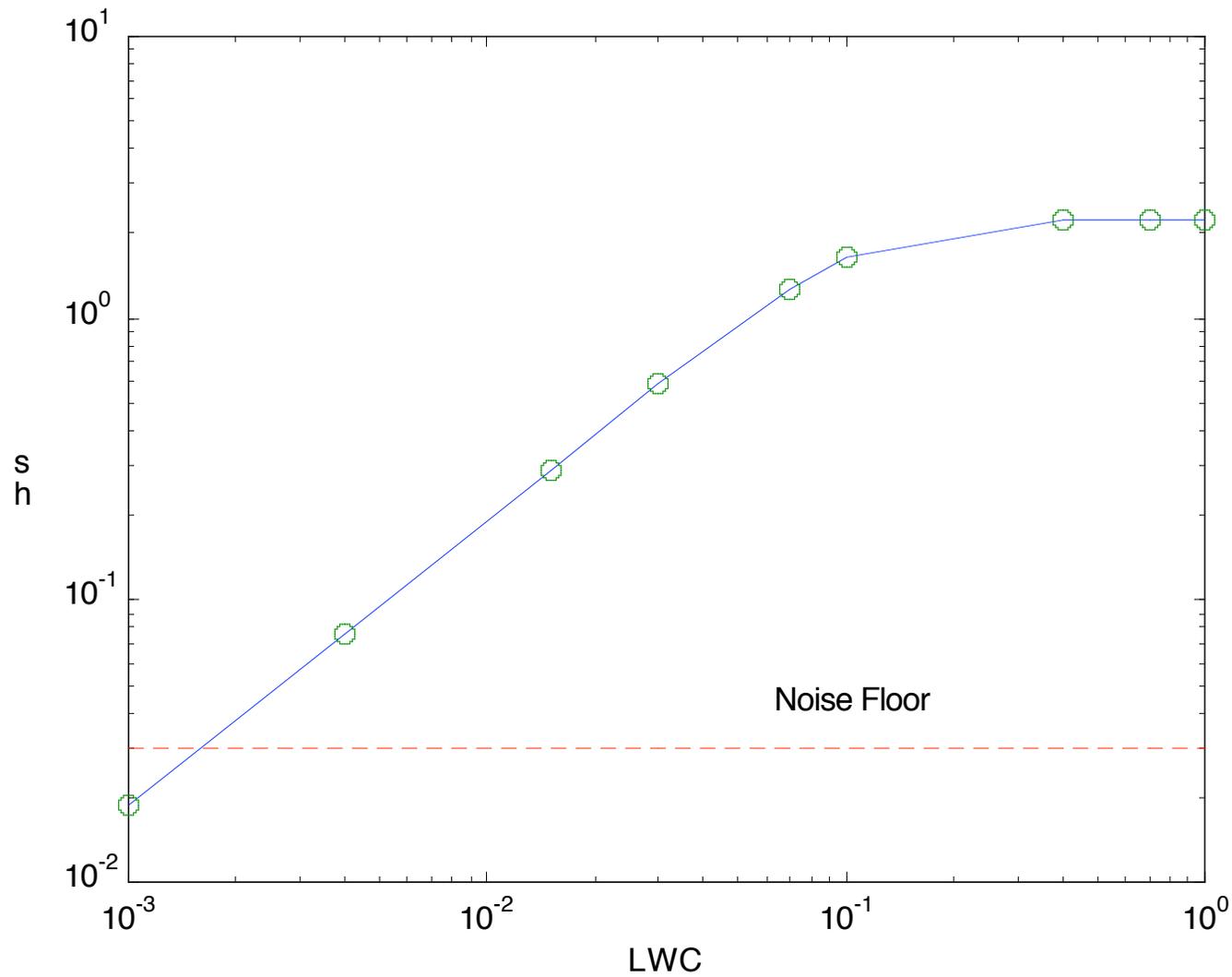
Water Medium Clouds, *hs* vs. LWC (g/m³)



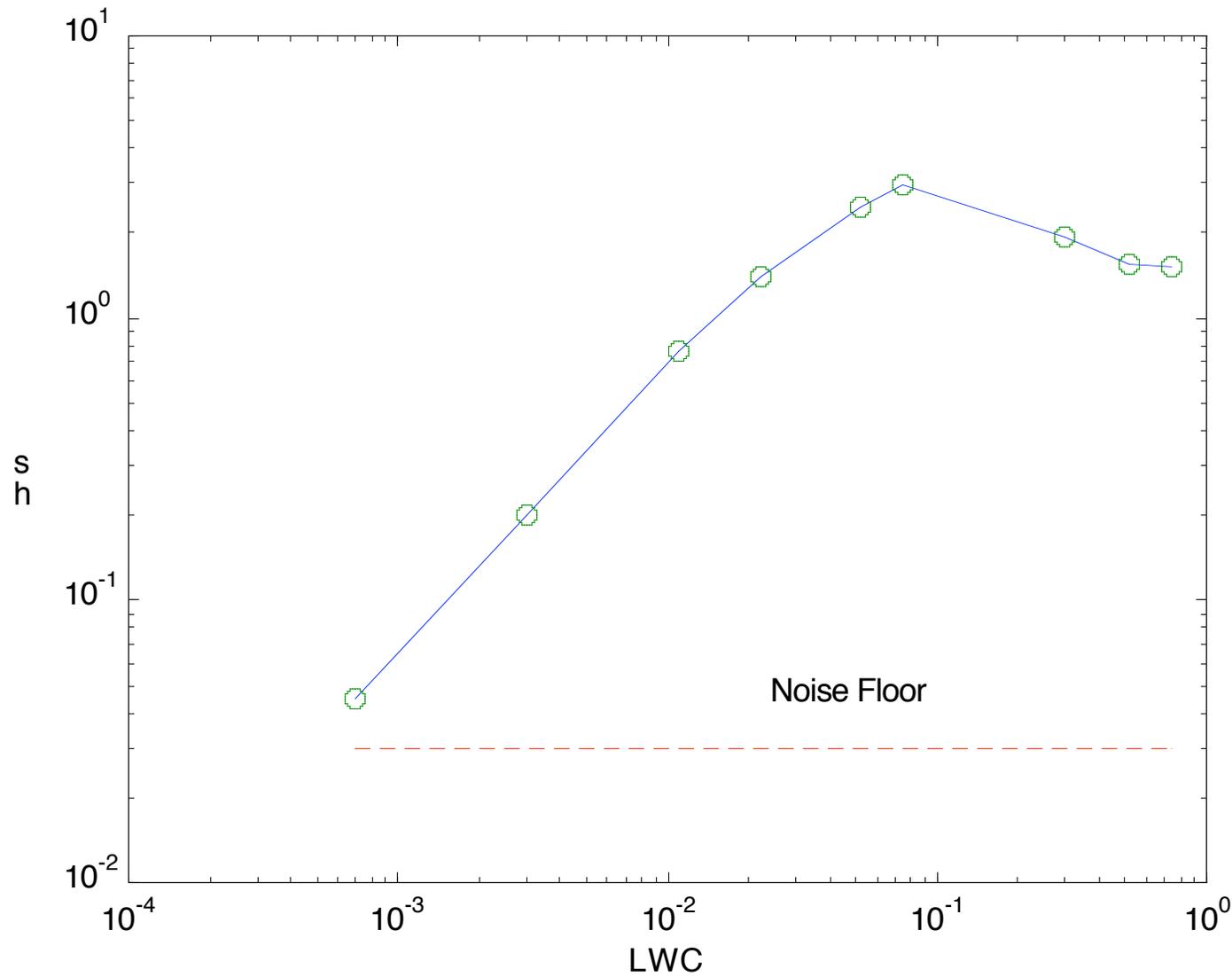
Water High Clouds, h_s vs. LWC (g/m^3)



Ice Medium Clouds, h_s vs. LWC (g/m^3)

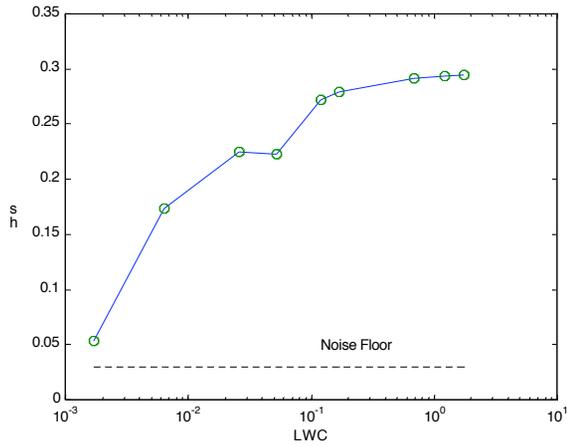


Ice High Clouds, h_s vs. LWC (g/m^3)

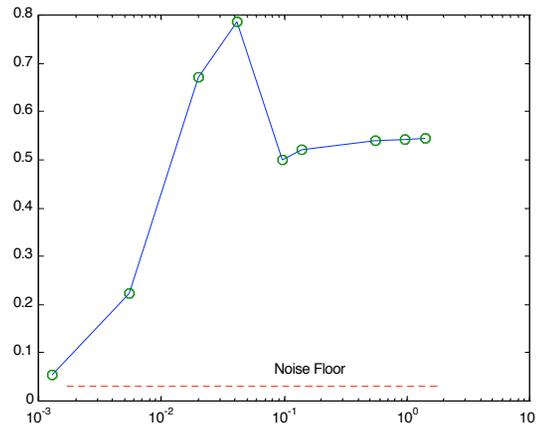


Summary

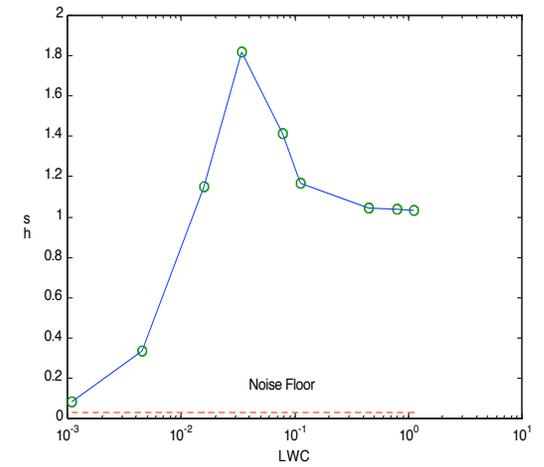
W3



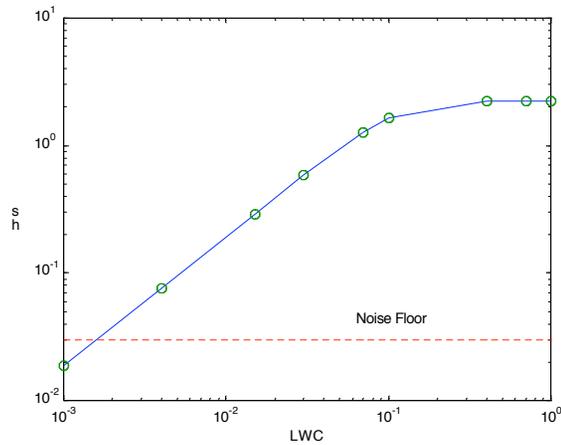
W2



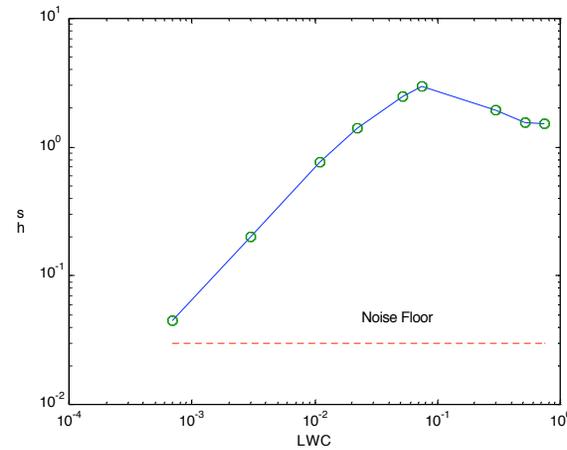
W1



I2



I1



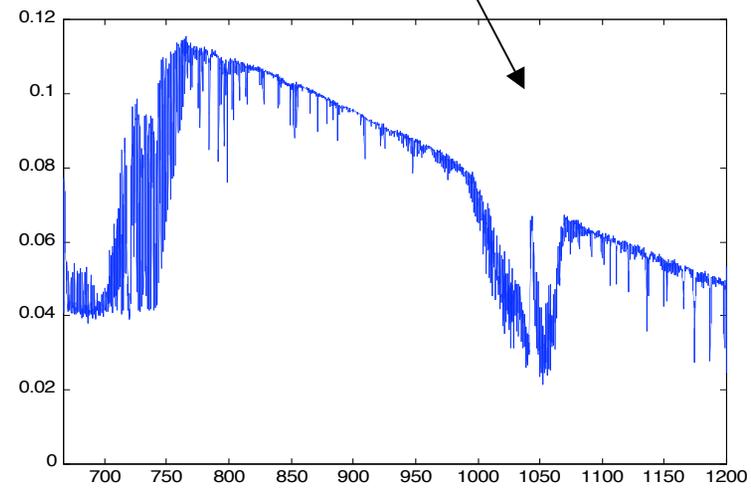
Inverting low hs spectra for geophysical parameter: $hs < 0.15$

- Analysis performed on the basis of IMG spectra
- Inversion obtained on the basis of the CHIARA methodology
- U. Amato, V. Cuomo, I. De Feis, F. Romano, C. Serio, H. Kobayashi, *IEE Trans. Geosci. Remote Sensing*, **37**, 1620-1632 (1999)
- A.M. Lubrano, C. Serio, A.S. Clough, H. Kobayashi, *Geophys. Res. Lett.*, **27**, 2533-2536 (2000)

Inversion Approach

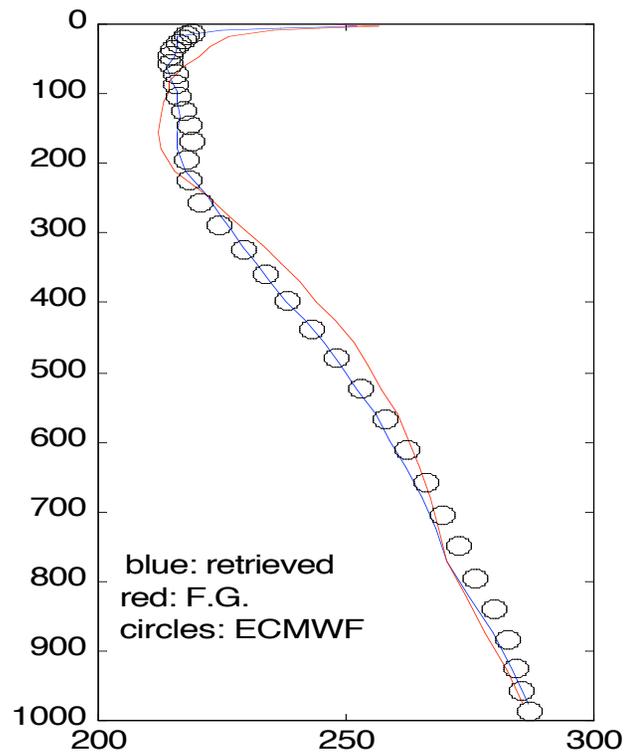
- **First Step**: Simultaneous retrieval of Temperature and Water vapour using the spectral interval $667\text{-}800\text{ cm}^{-1}$
- **Second Step**: Adjust for water vapour by retrieving water vapour using the spectral interval $1100\text{-}1200\text{ cm}^{-1}$

Mediterranean sea



Mediterranean sea, Obs 1

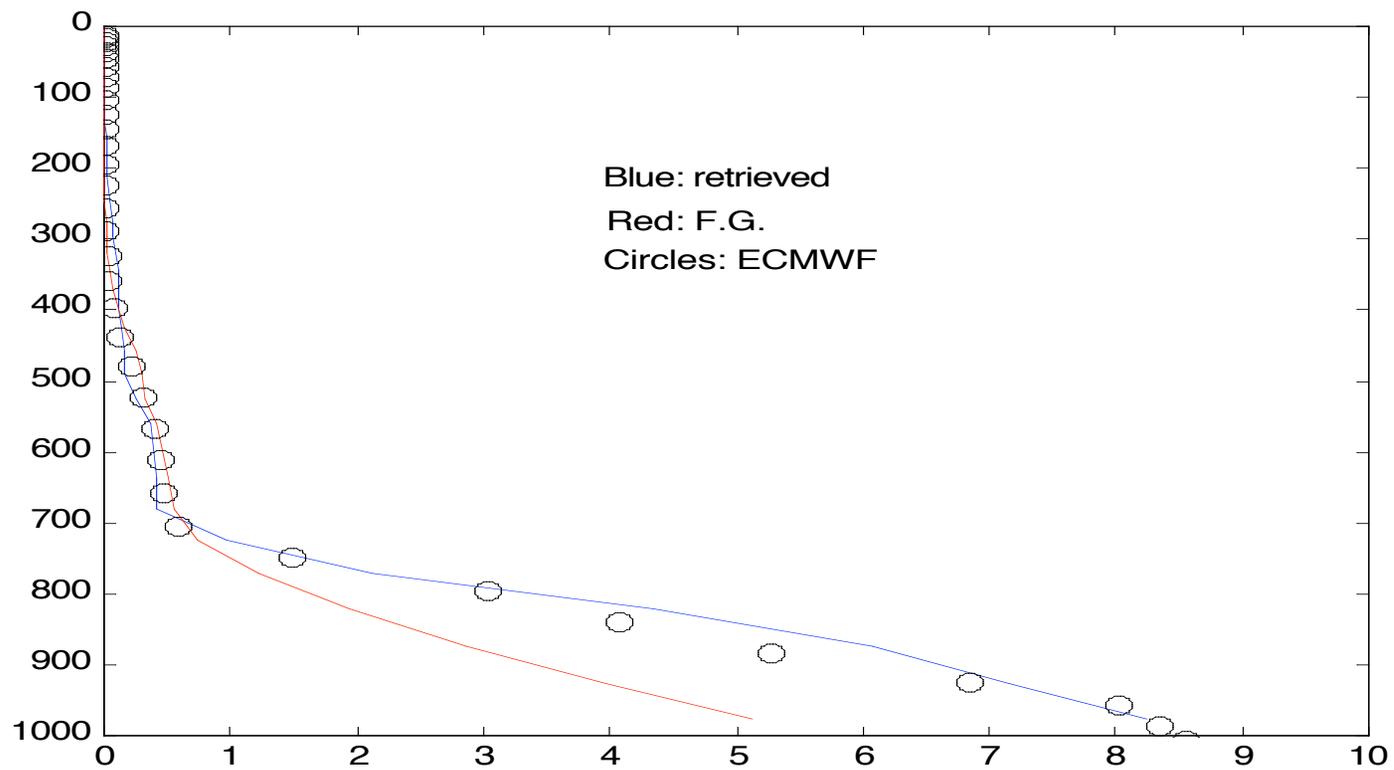
Temperature Retrieval



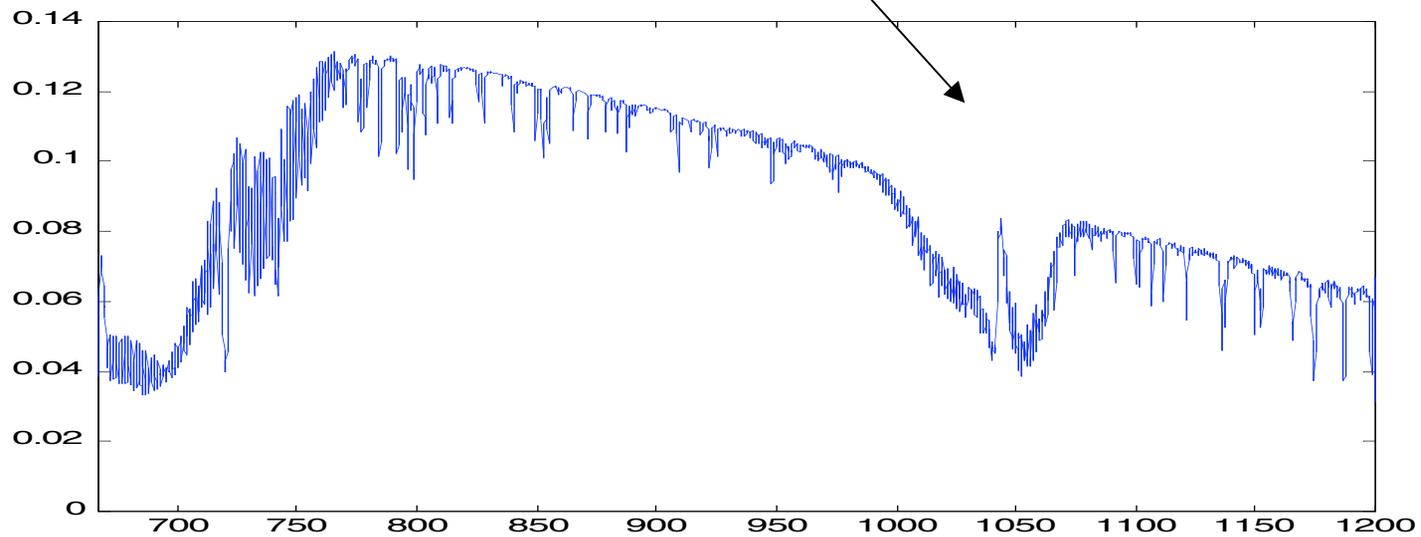
Skin Temperature: 287.8 (Ret,); 287.9 (ECMWF)

Mediterranean area, Obs 1

Water Vapour Retrieval

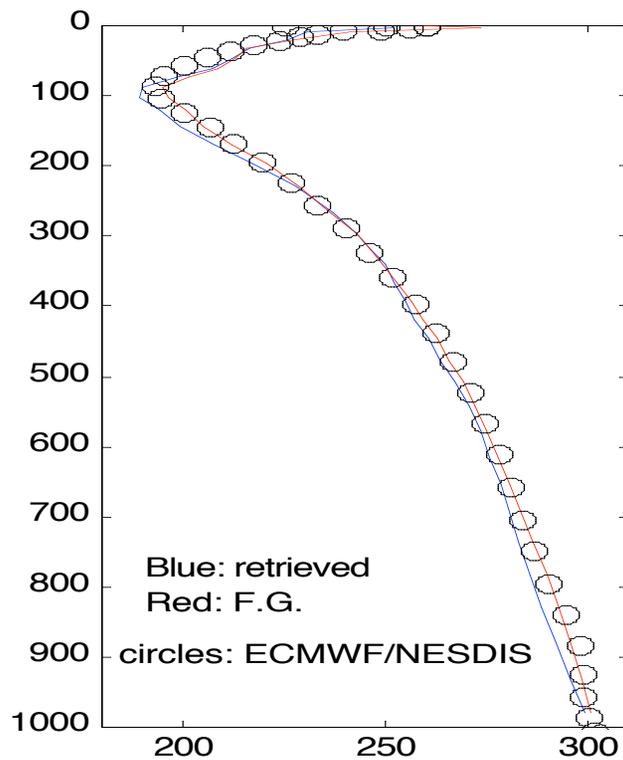


Tropical area, Indian Ocean



Indian Ocean sea, Obs 2

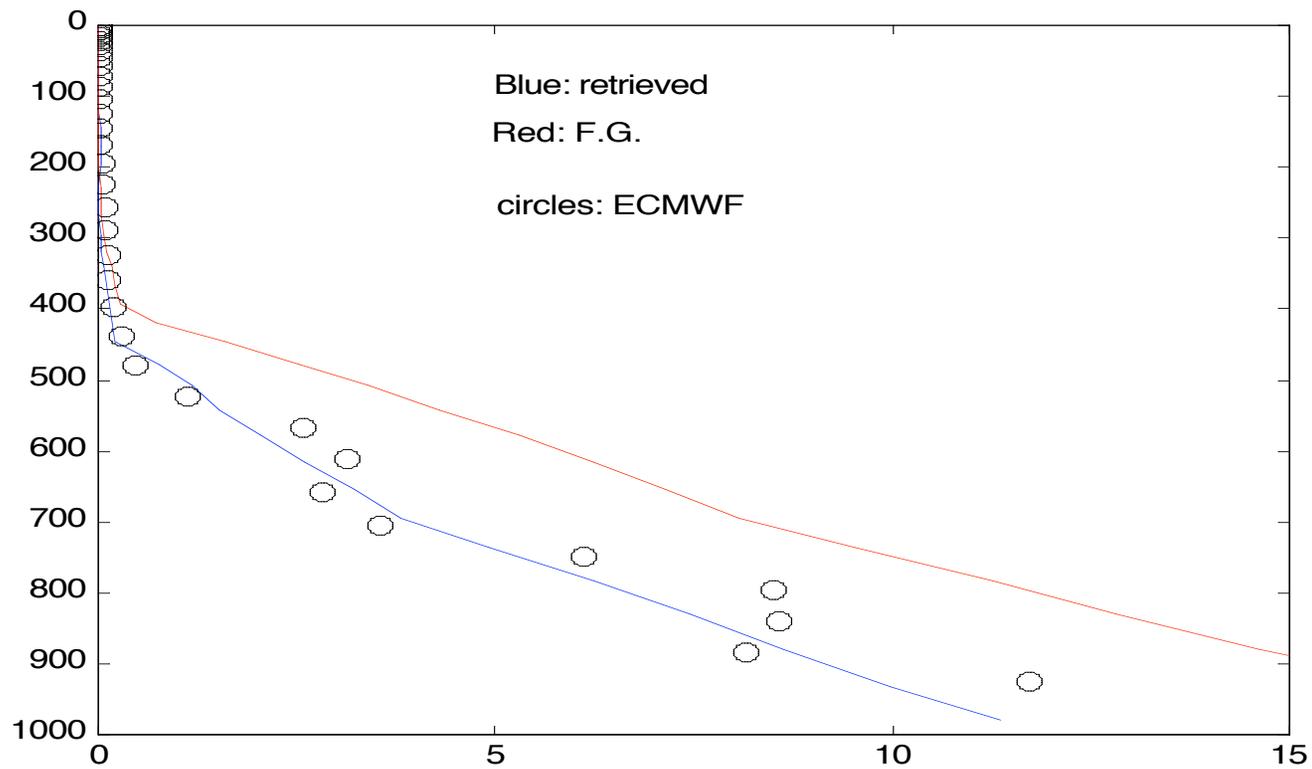
Temperature Retrieval



Skin Temperature: 302.0 (Ret.); 302.1 (ECMWF)

Indian Ocean sea, Obs 2

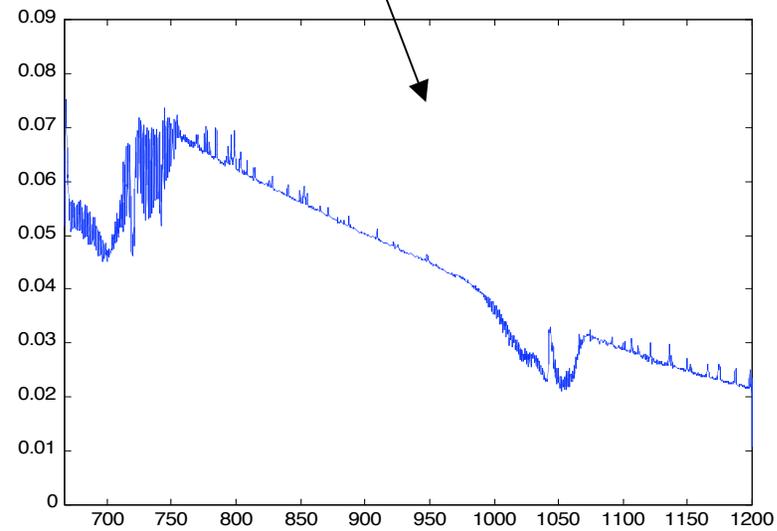
Water Vapour Retrieval



Arctic Region, Point Barrow, Alaska

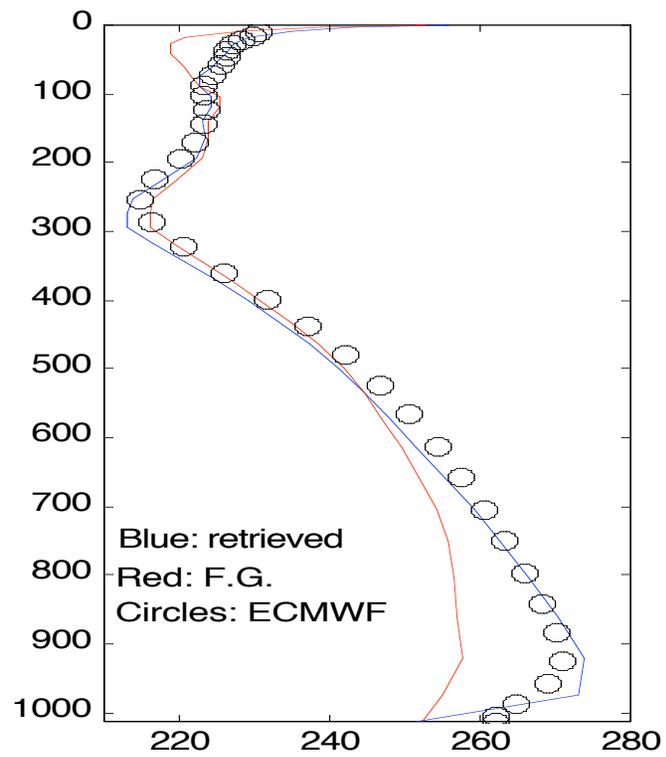


Obs. 1



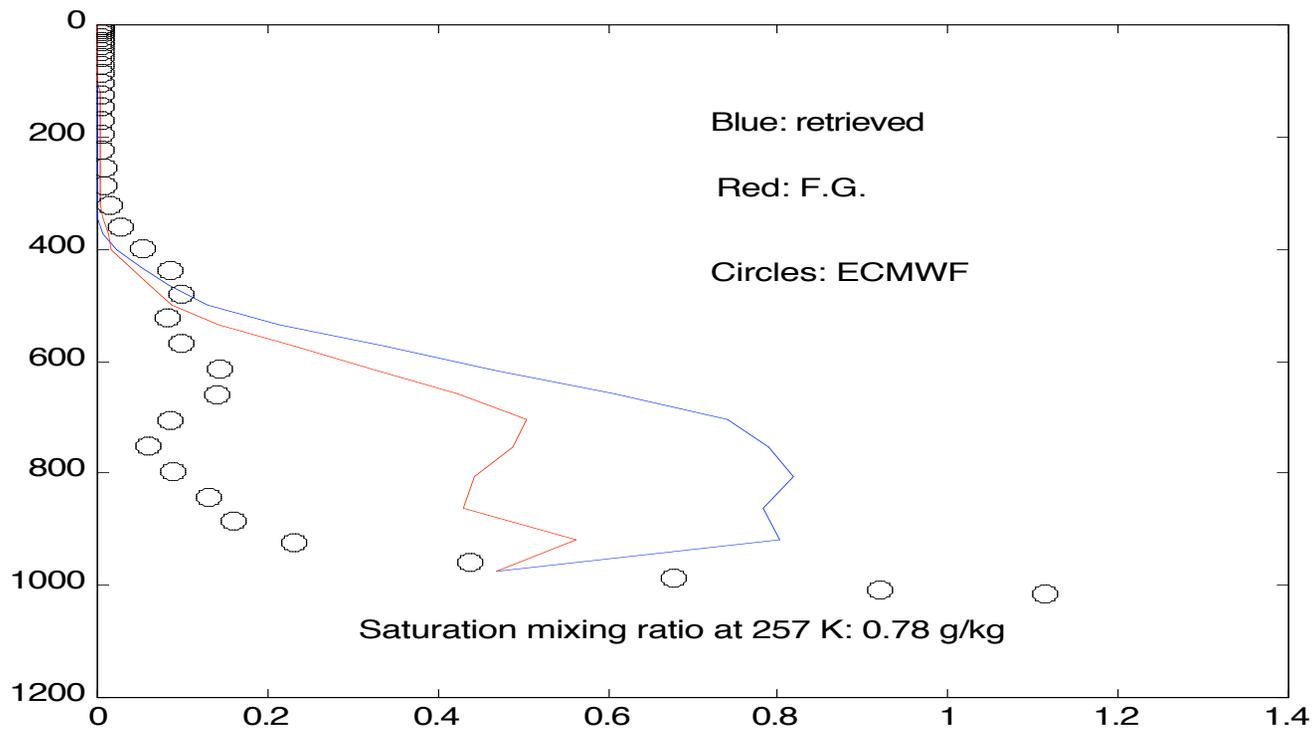
Arctic area sea-ice, Obs 1

Temperature Retrieval



Arctic area sea-ice, Obs 1

Water vapour Retrieval

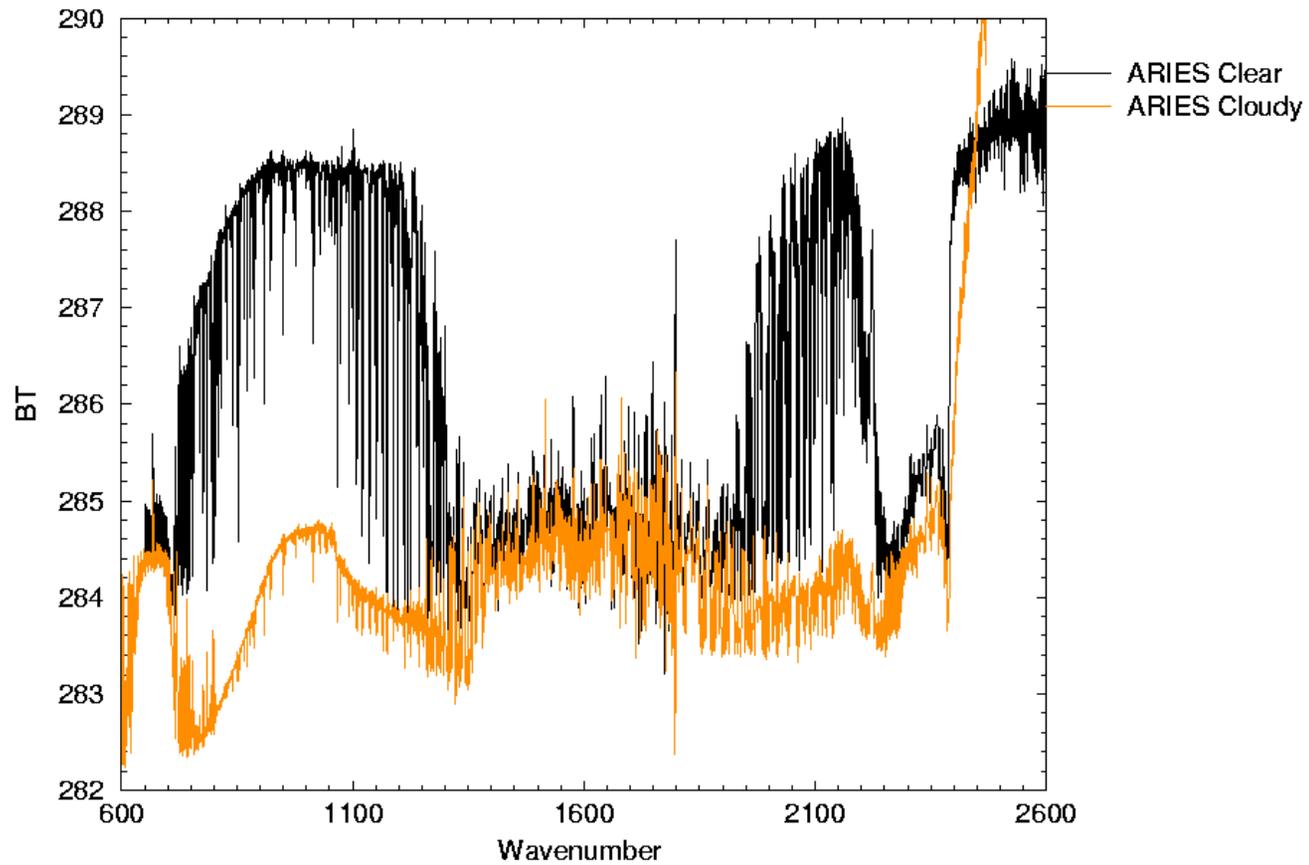


Conclusions

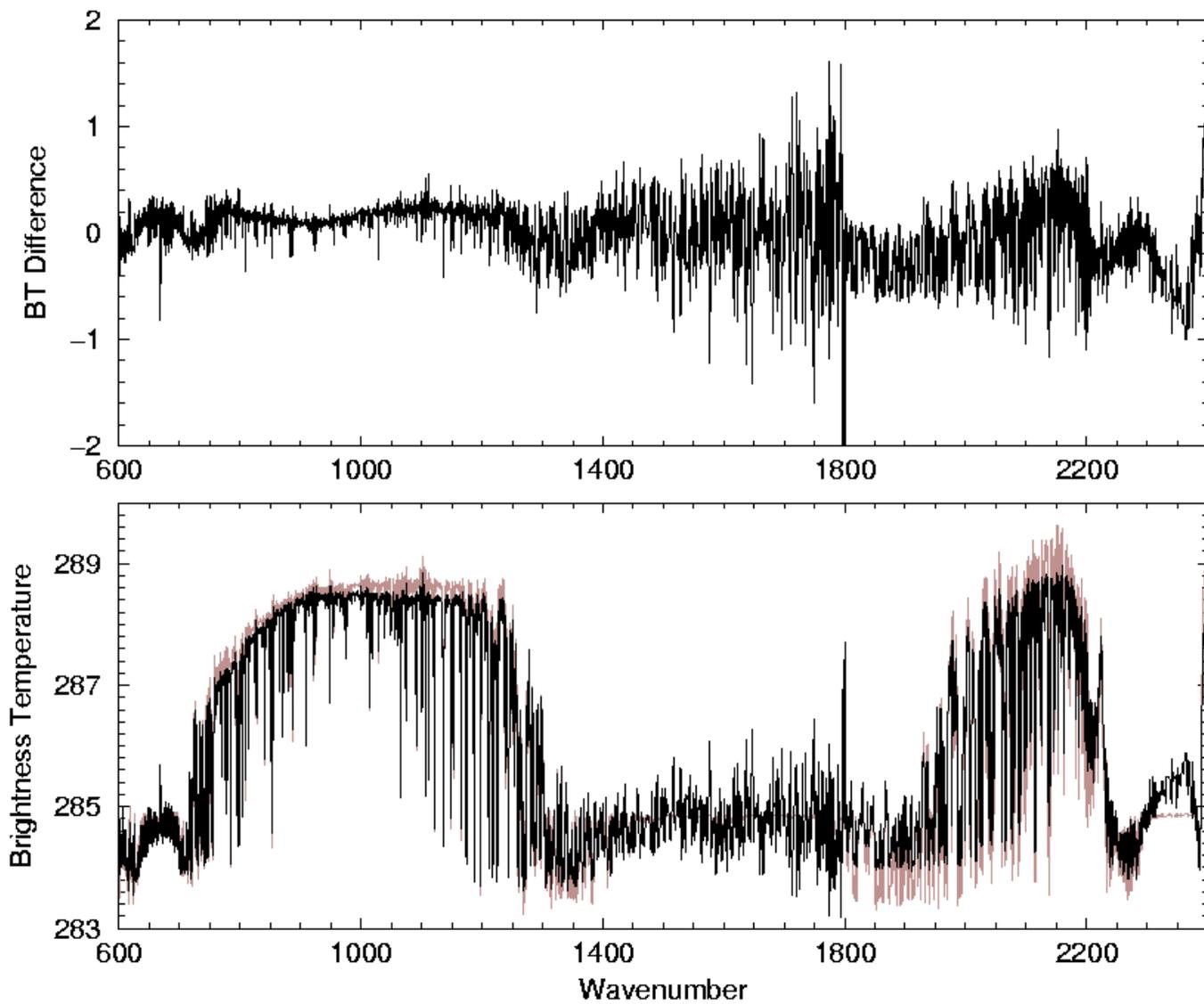
- We have devised a cloud detection scheme which exploits morphological characteristics of clear-sky radiance spectra
- The homomorphic index depends on the cloud amount
- The lesser the index is, the higher the given spectrum is homogenous to clear sky

Measured Clear and Cloudy Spectra

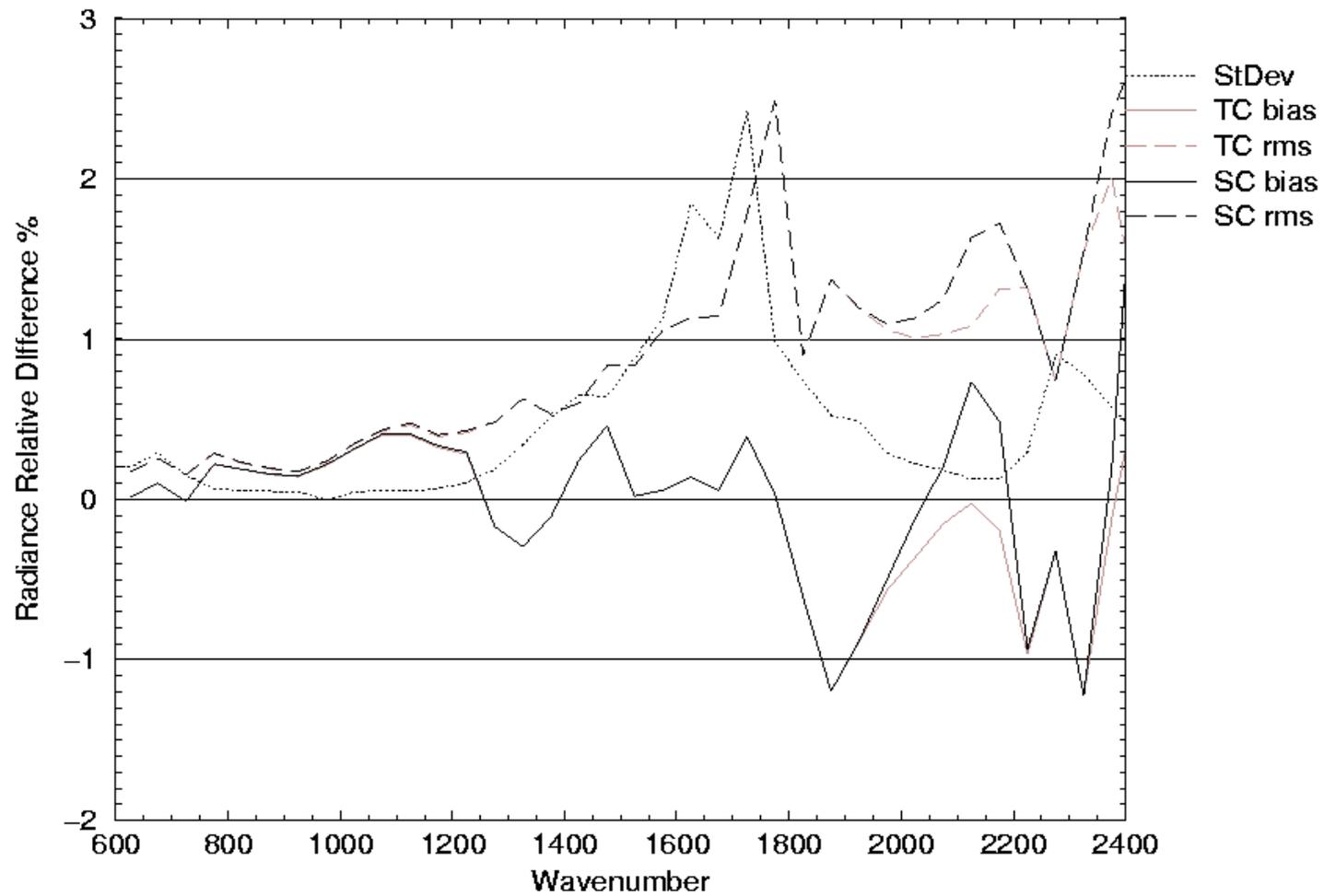
UKMO 623



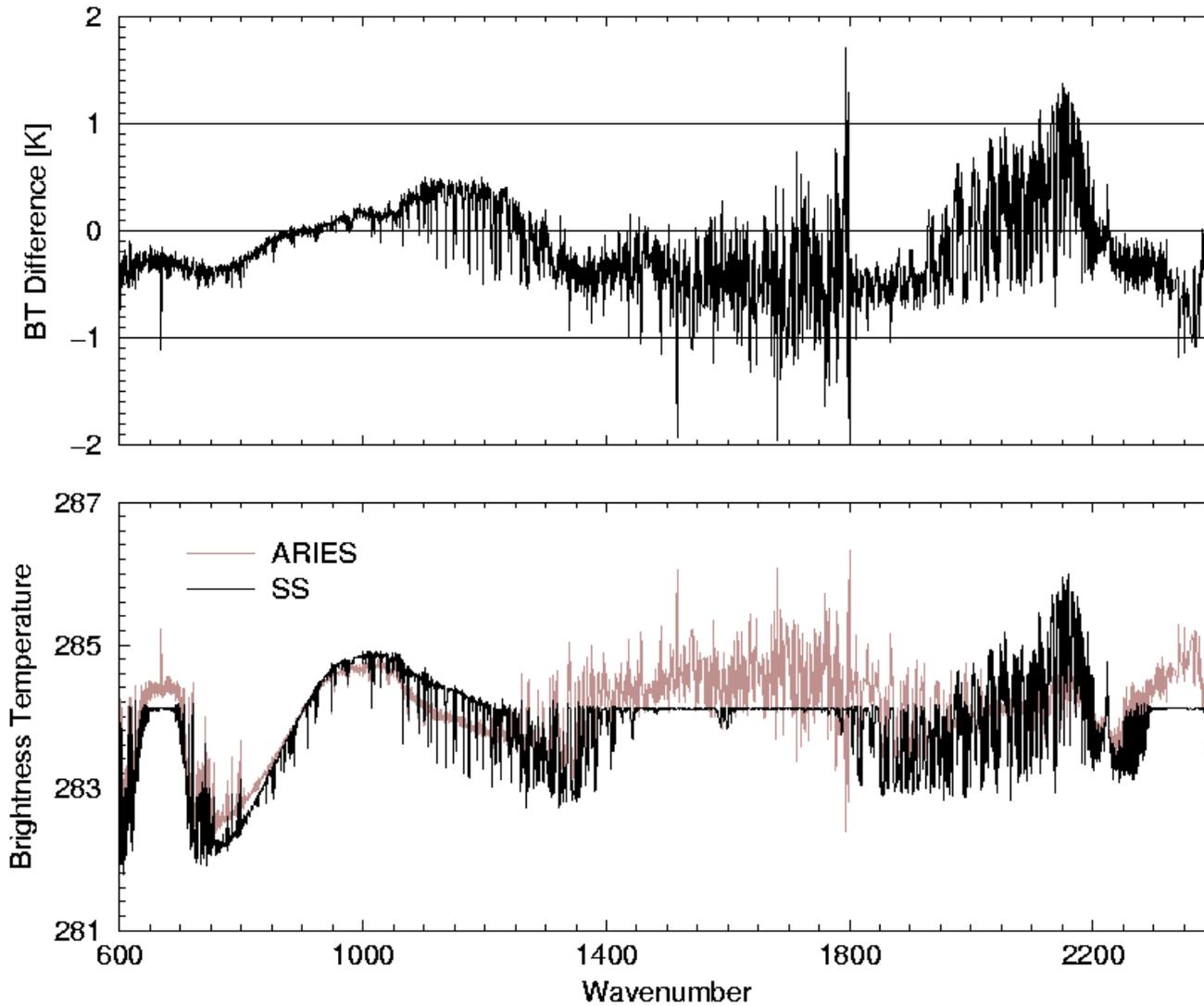
Clear Spectra



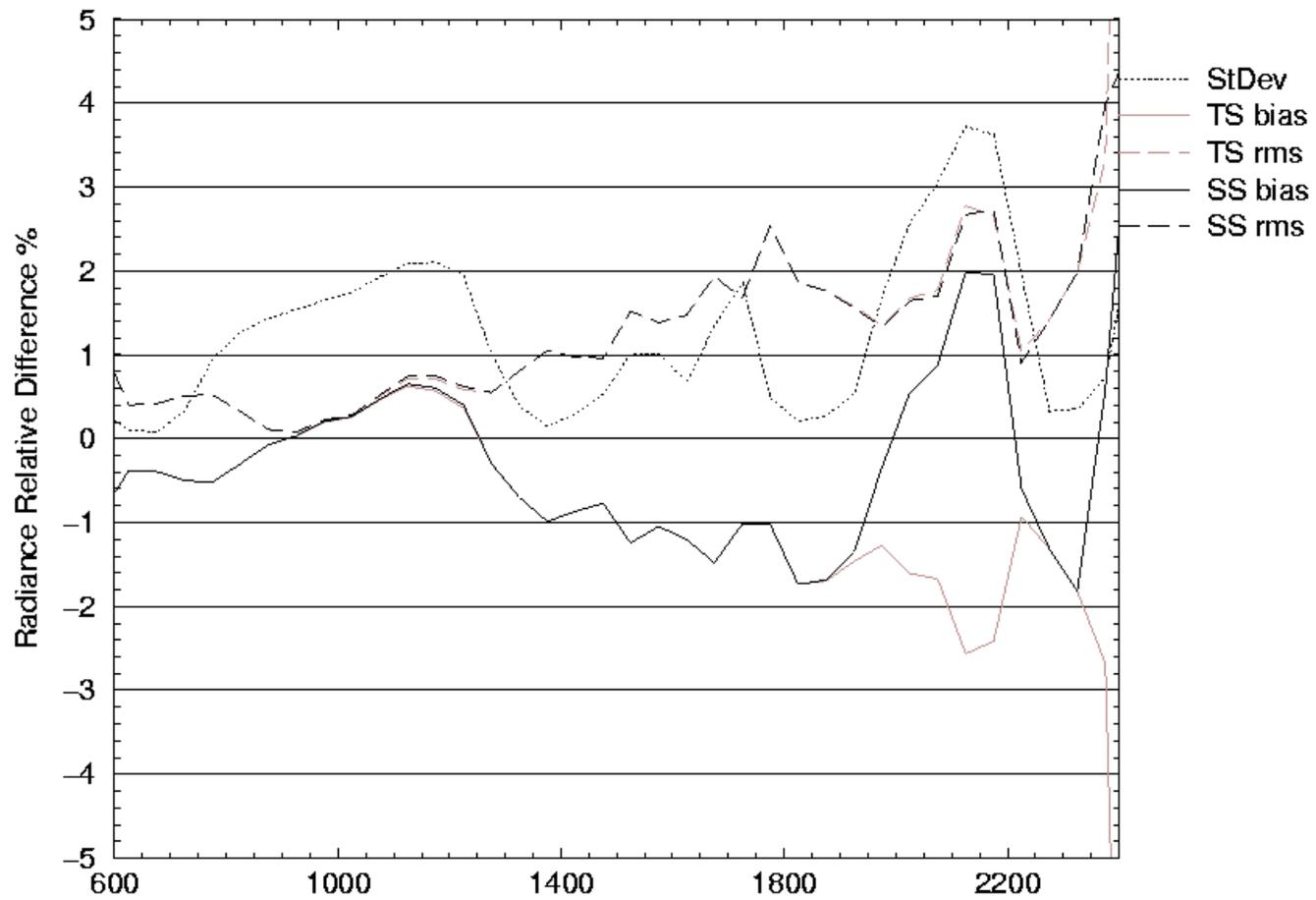
Clear Spectra stats



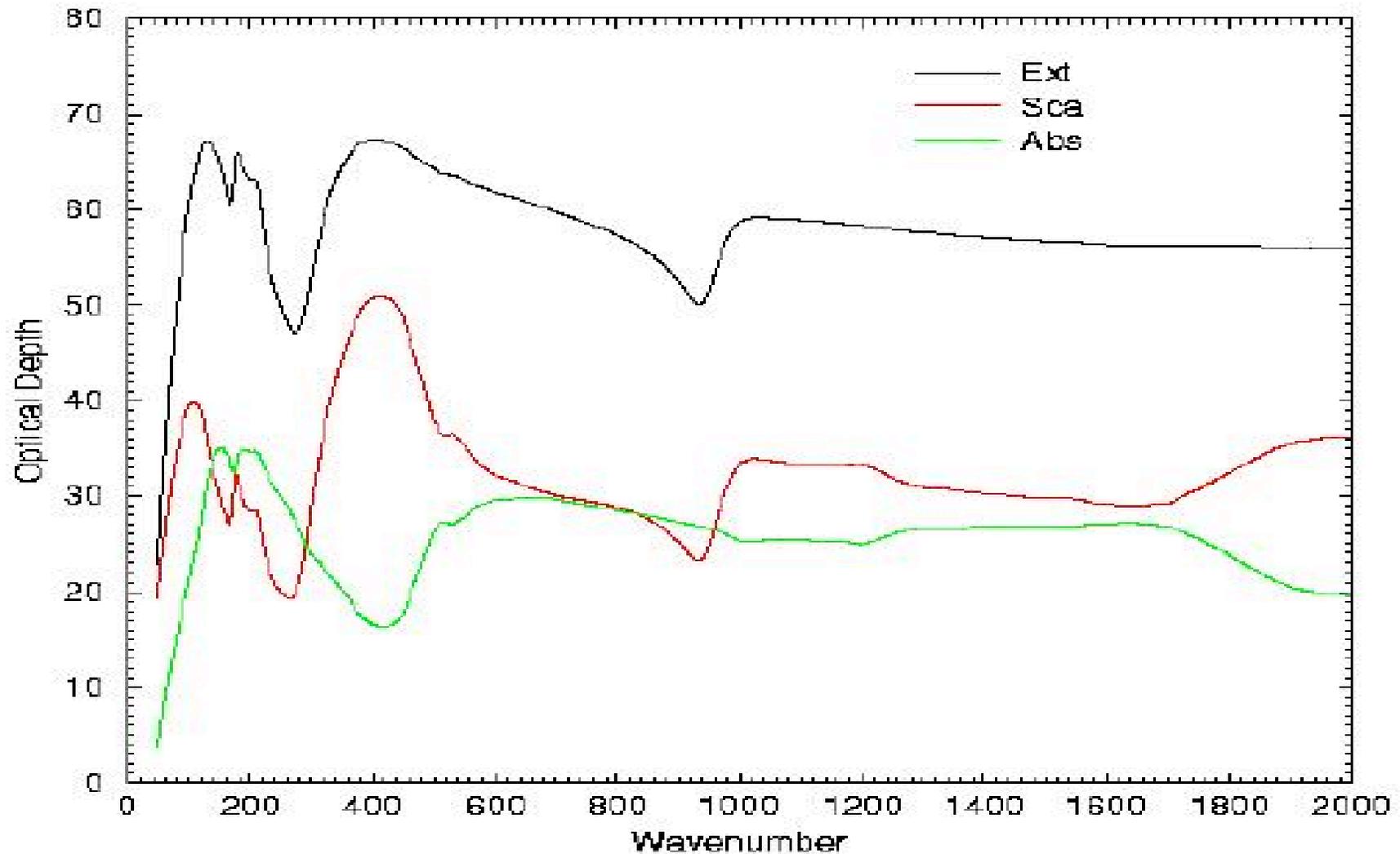
Cloudy Case LBLFS simulations



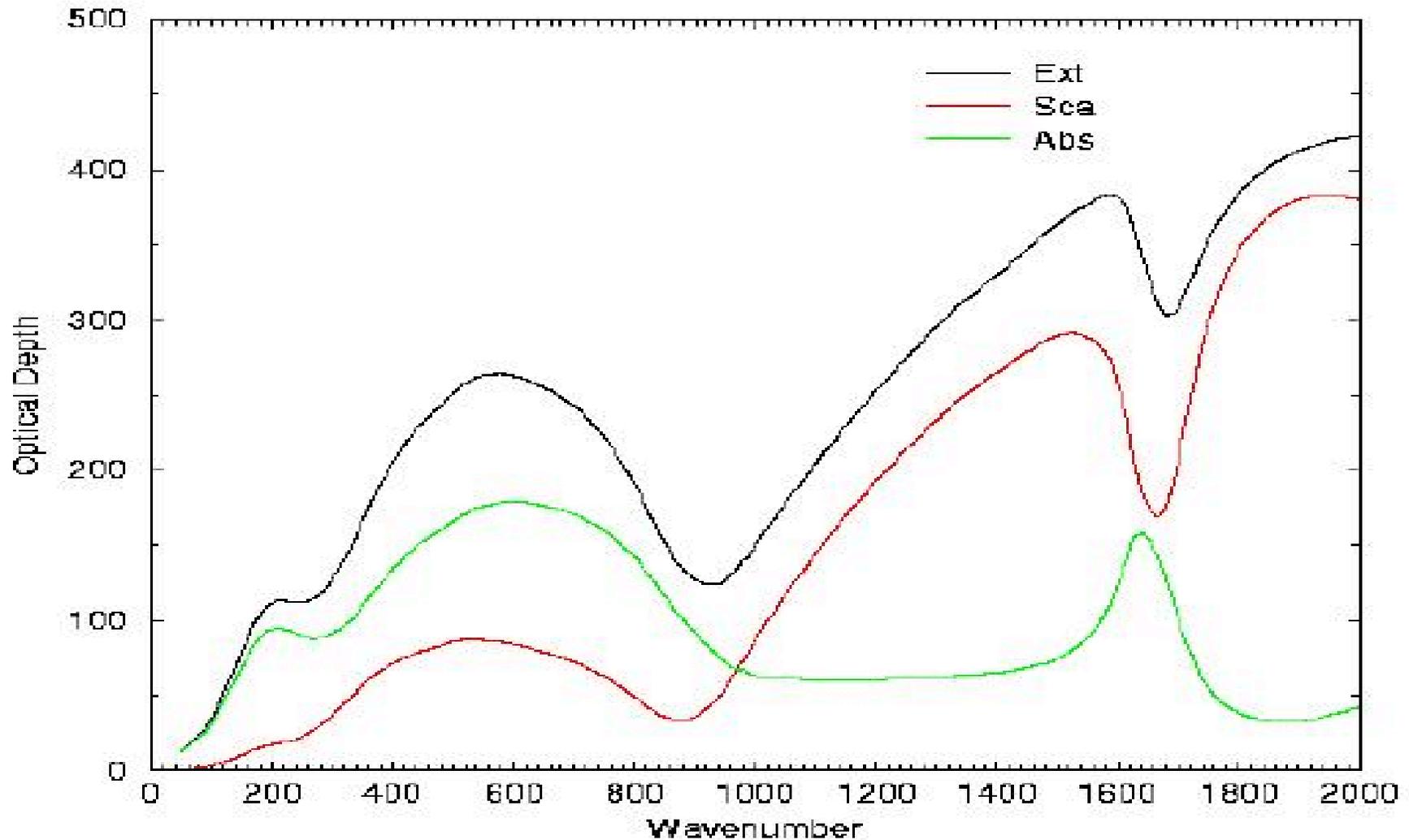
Cloudy Case Stats



Optical depth for cloud type I of depth 1 km



Optical depth for cloud type WH of depth 1 km



Optical depth for cloud type WL of depth 1 km

